CROWN MANAGERS PARTNERSHIP LANDSCAPES


August, 2013

A collaborative project between
National Park Service,
University of Calgary,
Crown Managers Partnership, and
US Fish and Wildlife Service Landscape Conservation Cooperative
Contents

Summary ......................................................................................................................................... 2
Background ..................................................................................................................................... 2
Purpose ........................................................................................................................................... 2
Involved Parties............................................................................................................................... 3
Data Inputs...................................................................................................................................... 3
  Grizzly bear occupancy data ....................................................................................................... 3
  Environmental Covariates ........................................................................................................... 4
    Preparation and Scale of Environmental Variables ................................................................. 5
Model Development ....................................................................................................................... 6
Model Results ................................................................................................................................. 7
Discussion of Model Covariates .................................................................................................... 11
Sources of Error ............................................................................................................................ 11
Work in Progress and Future Work .............................................................................................. 11
  Sensitivity Analysis ..................................................................................................................... 11
  Model of Relative Abundance ...................................................................................................... 11
  Conservation Planning Analysis .................................................................................................. 12
  Trend Monitoring ...................................................................................................................... 12
Other Objectives ........................................................................................................................... 12
  Management Questions .............................................................................................................. 12
  Geospatial Questions .................................................................................................................. 12
  Biology/Ecology Questions .......................................................................................................... 12
Further Reading ............................................................................................................................ 13
Summary

- We used transboundary datasets that cover the Crown of the Continent Ecosystem (CCE) to create a regional model of grizzly bear occupancy.
- Grizzly bear hair snag data were provided by collaborators in AB, BC, and MT.
- Logistic regression was used to model probability of grizzly bear occurrence using hair snag and landscape data.
- A list of covariates influencing broad scale patterns in occupancy was determined, as well as a map of predicted occurrence.

Background

The Crown Managers Partnership Landscape Analysis group has worked since 2009 to assemble and synthesize transboundary geospatial datasets to monitor ecological health. These datasets allow us to answer ecological questions that were previously not possible at the scale of the Crown of the Continent Ecosystem (CCE, Figure 1). Having assembled the Landscape Analysis data, the CMP is focused on applying the data to management questions that are shared across the CCE. We have undertaken a project to model grizzly bear (*Ursus arctos*) occupancy across the CCE to demonstrate the value of our landscape datasets.

Purpose

The purpose of this project was to develop a spatially explicit occupancy model for grizzly bears across the full extent of the CCE. The landscape occupancy model was created using ecological variables compiled for the CCE by the CMP and grizzly bear detection data provided by our partners in Alberta, British Columbia, and Montana. Our work identifies landscape-scale factors
that influence grizzly bear occupancy and compliments other fine-scale modeling activities occurring elsewhere in the CCE.

**Involved Parties**

- **Principle Investigators**: Garth Mowat (B.C. Forests, Lands and Natural Resource Operations), Kate Kendall (USGS, Northern Rocky Mountain Science Center), Gordon Stenhouse (Foothills Research Institute Grizzly Bear Research Program), Scott Nielsen (University of Alberta), Greg McDermid (University of Calgary)
- **Project Coordinator**: Erin Sexton (Crown Managers Partnership, Flathead Lake Biological Station)
- **Research Technician**: Will McInnes (Department of Geography, University of Calgary)
- **Data Manager**: Laura O’Gan (Rocky Mountain Inventory and Monitoring Network, National Park Service)

**Data Inputs**

This project required two types of data: Grizzly bear occupancy data from partners in Alberta, British Columbia, and Montana from 2004-2007; and environmental covariates derived from GIS and remote sensing.

**Grizzly bear occupancy data**

- Grizzly bear detections were defined from taken hair traps to provide consistent coverage across the CCE and sampling methodology. Rub trees were therefore excluded. See Table 1 for details on the numbers of hair trap samples and dates of collection, and Figure 2 for a land cover map displaying the sample locations of detected grizzly bears.
- Data are organized by session (i.e. each new location of a hair trap) and includes the number of males and females and the unique IDs for each individual bear found at each site.

<table>
<thead>
<tr>
<th>Principal Investigator</th>
<th>Region</th>
<th>Year(s)</th>
<th>Detection Rate</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katherine Kendall</td>
<td>Montana</td>
<td>2004</td>
<td>0.1551</td>
<td>2566</td>
</tr>
<tr>
<td>Garth Mowat</td>
<td>BC</td>
<td>2007</td>
<td>0.4597</td>
<td>124</td>
</tr>
<tr>
<td>Gordon Stenhouse</td>
<td>Alberta/BC</td>
<td>2006/2007</td>
<td>0.2122</td>
<td>820</td>
</tr>
</tbody>
</table>
Figure 2: Grizzly bear hair snag locations in the Crown of the Continent Ecosystem (2004-2007).
Environmental Covariates

Environmental predictors were grouped into three ecological categories (themes). These included:

- Ecosystem Productivity
  - Climate
  - Geology (can predict food sources)
  - Terrain
  - Net Primary Productivity
- Habitat
  - Land use
  - Land cover heterogeneity (number of different classes within a moving window)
  - Vegetation types (land cover)
  - Forest disturbance (fire and mountain pine beetle)
- Human Disturbance
  - E.g. roads, trails and tracks
  - Other human impacts

Preparation and Scale of Environmental Variables

The scale of individual environmental variables in the model is critical. Many of the environmental variables have an original grain size of 30m, but it is unlikely that grizzly bears interact with all aspects of their environment at this fine scale (Nielsen et al., 2010). In general, organisms interact with their environments at a variety of scale, and there is no single appropriate scale for all variables that will best explain occupancy (Zeller et al., 2012). To determine what scale environmental variables are most significant to grizzly bears, variables were summarized at three different scales that previous research determined to be important to grizzly bears. Figure 2 shows how the variables were summarized at these circular radii and the effect of this summary on the resulting new layer. The three scales used were:

- 300m circular radius: best predictor of occupancy (Nielsen et al., 2010)
- 1.69 km circular radius: detection scale for hair snag sites (Boulanger et al., 2004)
- 10km circular radius: 90% kernel home range size of female grizzly bears (Nielsen et al., 2010)

Distance to polygon edges and edge densities of vector datasets were also calculated.
Model Development

Probability of occurrence of grizzly bears was estimated for the CCE using logistic regression with landscape environmental variables collected by the CMP predicting the presence or absence (undetected) of bears at a hair trap. No attempt was made to estimate detectability (detected given present) and thus estimates are likely to be under-estimates of true occupancy (MacKenzie et al. 2006). We also assume that detectability is not influenced by the same landscape covariates used to model occupancy and thus relationships between occupancy and environmental covariates are robust. Modeling efforts were led by Scott Nielsen of the University of Alberta.

Multiple candidate models were built testing the variables at three pre-defined scales (300m, 1.69km, 10km circular radius) to determine at what scale they were most significant. Additional models were built to test select non-linear relationships between variables and grizzly bear occupancy. These non-linear relationships were selected using knowledge of grizzly bear biology. For example, grizzly bear occupancy may be best predicted by a particular range of values of a variable (i.e. temperature); in this case a quadratic model would be needed to describe the intermediate peak (figure 4). In other cases, non-linear relationships between variables can be used to extract more information about grizzly bear occupancy. For example,
if elevation and forestry cut blocks were combined we might find that grizzly bear habitat is more accurately predicted by cut blocks at higher elevations (i.e. mountainous regions) versus those at lower elevations.

The significant variables were combined into models based on their categories: ecosystem productivity, habitat, and human disturbance using the methods described by Nielsen (2010) and Hosmer and Lemeshow (2000). The three models were then combined, and non-significant variables removed for development of a final model. Model parameters were used to develop a map predicting the probability of grizzly bear occurrence across the CCE.

**Model Results**

The variables that are significant in predicting grizzly bear occupancy across the CCE are listed below along with a brief explanation of each. The associated coefficients, standard error, and statistical significance scores for each variable are shown in Table 2 and the map of predicted probability of occurrence of grizzly bears in the CCE show in Figure 5.

Overall, the model developed has a good fit. The area under the Receiver Operating Characteristic (ROC) curve for the model is 0.767; this means that 76.7% of the time the model can correctly differentiate between sites that are occupied by grizzly bears and those that are not (Pearce & Ferrier, 2000).

**Positive relationship between occupancy and the following variables:**

- Heterogeneity of landcover classes within 300m: occupancy increases as heterogeneity in land cover classes increase within a 300m radius.
  - This variable represents the number of different land cover classes within a circular window of 300m. This relationship might occur because higher heterogeneity occurs in regions of edges and disturbed habitats that are known to associated with grizzly bear habitat.

- Proportion of protected areas within 10km: occupancy increases with proportion protected within a 10 km radius.

- Distance to nearest high capacity road: occupancy is higher further from high capacity roads.
Inverse (negative) relationship between occupancy and the following variable:
- Proportion of cultivated areas within 10km: as proportion cultivated area increases within a 10 km radius, occupancy of bears decreases.

Non-linear relationships between occupancy and the following variables:
- Mean Average Temperature (MAT) + Mean Average Precipitation (MAP) – (MAT * MAP)
- Net Primary Productivity (NPP, aggregated to 1.69km) + NPP²: There is an intermediate range of NPP which best predicts grizzly bear occupancy.
  - NPP is a measurement of the vegetation’s net use of carbon. A positive NPP indicates an uptake and storage of carbon, which in turn indicates plant growth.
- Distance to Mountain Pine Beetle (MPB) Disturbance + √Distance to MPB disturbance
- Terrain Ruggedness Index (TRI) + TRI²: There is an intermediate range of TRI that best predicts bear occupancy.
  - TRI describes the difference in elevation between adjacent cells. The greater the difference in elevation, the more rugged the terrain, and the higher the TRI.
- Distance to nearest well * MAP – distance to well: This relationship might be because bears tend to occur in disturbed areas (e.g. well sites), but only in the mountains where precipitation is higher.
Table 2 Variables included in the final grizzly bear occurrence model. In this table it is important to note the sign of the coefficient of each variable, as well as the z score, where a larger number means more confidence in the variable.

| Variable                                      | Ecological Categories | Coefficient | Std. Err. | z   | P>|z| |
|-----------------------------------------------|-----------------------|-------------|-----------|-----|-----|
| Mean Annual Temperature (MAT)                 | Ecosystem Productivity | 0.067592    | 0.032161  | 2.1 | 0.036 |
| Mean Annual Precipitation (MAP)               | Ecosystem Productivity | 0.006622    | 0.002183  | 3.03| 0.002 |
| MAT*MAP                                       | Ecosystem Productivity | -0.00011    | 4.72E-05  | -2.26| 0.024 |
| Net Primary Productivity (NPP) aggregated to 1.69km | Ecosystem Productivity | -2.74366    | 0.951838  | -2.88| 0.004 |
| NPP²                                          | Ecosystem Productivity | 1.670864    | 0.623289  | 2.68| 0.007 |
| Distance to Mountain Pine Beetle (MPB)         | Habitat               | -0.09337    | 0.021907  | -4.26| 0   |
| Square Root of distance to MPB disturbance     | Habitat               | 0.49212     | 0.131713  | 3.74| 0   |
| Number of different landcover classes within 300m window | Habitat               | 0.119948    | 0.039944  | 3   | 0.003 |
| Proportion of cultivated area within 10km      | Habitat               | -8.06475    | 2.466728  | -3.27| 0.001 |
| Proportion of protected area within 10km       | Habitat               | 0.749442    | 0.18693   | 4.01| 0   |
| Distance to nearest well                       | Human Disturbance     | -0.21568    | 0.046065  | -4.68| 0   |
| Distance to nearest high capacity road         | Human Disturbance     | 0.010455    | 0.004421  | 2.36| 0.018 |
| Terrain ruggedness index averaged over 10km    | Ecosystem Productivity | -1.44612    | 0.62875   | -2.3 | 0.021 |
| Terrain ruggedness index averaged over 10km squared | Ecosystem Productivity | 0.177916    | 0.072898  | 2.44| 0.015 |
| MAP * distance to well                         | Ecosystem Productivity + Human Disturbance | 0.000298    | 6.74E-05  | 4.43| 0   |
| Constant                                      |                       | -3.183      | 2.038455  | -1.56| 0.118 |
FIGURE 5 MODELED GRIZZLY BEAR OCCUPANCY IN THE CROWN OF THE CONTINENT ECOSYSTEM.
Discussion of Model Covariates

The nature of the final CCE grizzly bear occupancy model necessitated that covariates be broad enough that they could be applied across the entire region. At the regional scale, the importance of factors affecting the occurrence of grizzly bears such as terrain, precipitation, and vegetation productivity can be seen. A few variables relate to disturbance and edges. These variables include heterogeneity of land cover, distance to MPB disturbance, and distance to wells. Land use and human footprints also affected occupancy. This includes distance to high capacity roads and proportion of protected areas and cultivated areas within a 10km radius.

Specific to management and monitoring initiatives, the human and disturbance factors are important measures to consider. Although this analysis did not include many local variables, it is apparent that regional environmental variables are applicable to monitoring grizzly bear occupancy in the CCE. Small-scale evaluations of models applied to sub regions of the CCE illustrate that variable importance varies by region. One variable that needs further exploration is timber harvests, because it has been found to be influential in Alberta studies. Inconsistent data in Montana restricted our ability to include timber harvests in this model.

Sources of Error

- Uncertainty and inconsistency in the geospatial data
- Grizzly bear sampling – differences across studies.
  - While the data are fairly consistent, there may be some biases in the way that data was collected or sites were selected.

Work in Progress and Future Work

Sensitivity Analysis

- We aim to examine how uncertainty in the geospatial data would propagate to final models by performing a sensitivity analysis.
  - What is the effect of inconsistent data collection methodology across the CCE?
  - How does the accuracy of the Landover map affect the final map?

Model of Relative Abundance

- We aim to model relative abundance of grizzly bears across the CCE using count data of unique bears from hair snag data (number of unique individuals detected per site). This will be led by Scott Nielsen.
Conservation Planning Analysis
- Conduct a regional conservation planning analysis to identify and prioritize areas for conservation. This will be led by Scott Nielsen.

Trend Monitoring
- Conduct broad-scale landscape trend monitoring by back-casting and fore-casting landscape indicators across the CCE.

Other Objectives

Management Questions
- What are the primary predictors of abundance and occupancy for each management area?
- What predictors should be monitored over time?
- What is the productivity of the areas in the CCE where we don’t see bears?
- Where are potential habitats for expanding bear populations?
- What is the value of parks or protected areas versus “other” (i.e. provincial/state land)?

Geospatial Questions
- What level of timber harvest (seral stage of forest) predicts bear occupancy?
- How does the relationship between forestry and occupancy/abundance change across the CCE?
- Do NPscape metrics predict grizzly bear occupancy?
  - Are there other remotely sensed productivity metrics that can predict occupancy and abundance?

Biology/Ecology Questions
- Where do the Landscape metrics predict bear occupancy?
- Where do the Landscape metrics fail to predict occupancy?
- What are the controls on local factors of carrying capacity and abundance across different jurisdictions and regions, within the same genetic unit?
- How do local and global models fit?
- How do our models compare to higher effort local models created in previous studies?
Further Reading


